# ADHESIVE BEHAVIOR IN AIRCRAFT APPLICATIONS

*John Tomblin, Waruna Seneviratne*
*Wichita State University, Wichita, KS*

*Hyonny Kim*
*Purdue University, West Lafayette, IN*

## Introduction

There is a growing application of composite materials in airframe structures, especially for small aircraft. These composite airframe components tend to make significant use of bonded construction for both improved structural efficiency and reduced manufacturing cost. The situation is exemplified by activities of the NASA Langley Advanced General Aviation Transport Experiments (AGATE) Integrated Design and Manufacturing (ID&M) consortium for which the FAA provides technical support, with the participation of various members of the small aircraft manufacturing community currently developing specific applications of composite construction of new aircraft. These aircraft make major use of bonded construction.

Various certification-related issues arise in these applications of adhesive joining: (1) for small manufacturers there is a trend toward the use of unusually large bond layer thicknesses which are beyond the range for which structural performance data are readily available; (2) surface preparation methods for bonding of composites may involve the use of a removable peel ply which can sometimes lead to poor structural reliability of the adhesive joint; (3) the behavior of various test methods for characterization of mechanical properties of adhesives needs clarification; (4) there is a general lack of agreement on stress analysis methods and failure criteria for design of adhesive joints; (5) with these relatively large bondlines, the effect of bondline thickness variation has not been characterized; (6) environmental effects of ìlow temperatureî cure adhesive with respect to the aircraft or component maximum operational limit are unknown; (7) the damage tolerance of the bonded aircraft components with respect to joint structural safety and durability is unknown; (8) the effect of fatigue on thick bondline joint has not been characterized or investigated; and (9) the effects of creep on thick bondline joints has not been characterized or investigated.

Current studies on adhesive behavior in aircraft applications conducted under this part of the program address the following certifications related issues:

- Characteristic shear responses of structural adhesives and effects on mechanical properties on temperature and humidity
- Fatigue behavior of thick bondline at high stress levels
- Creep behavior of thick bondline
- Structural response of adhesive lap joint under torsion

The first three issues were addressed in Program A (coupon level testing) defined as Task 1, 2, and 3, respectively and the last in Program B (sub-component testing).

**Task 1: Characteristic Shear Responses of Structural Adhesives**

Figure (1) depicts the wide variation of adhesive shear properties with respect to different environmental conditions. As seen from Figure (1), this wide variation not only changes yield strength but ductility drastically changes. This type of behavior could not only influence the adhesive performance but also the failure mode.

This task generated characteristic shear responses at three different environmental conditions for eighteen different structural adhesives that are currently being used or proposed for use in manufacturing applications, as well as several that have been used historically in aircraft primary structural bonding. Six of these adhesives were film and the remaining adhesives were paste. In addition, the effects of heat and humidity on the apparent shear strength, shear modulus, and failure modes of each adhesive were investigated.

The adhesive strength and modulus were calculated according to ASTM D5656. Testing was conducted in three different environmental conditions: room temperature dry (RTD), elevated temperature dry ~ 180  F (ETD), and elevated temperature wet ~ 180  F (ETW). This data will provide useful information with ongoing certification issues related to application of lower temperature cure adhesive systems. This information will also be useful in generating analytical models related to adhesive bonding. The results were summarized in a FAA technical report, which is currently under review.

**Task 2: Effect of fatigue on thick bondline joints**

Since adhesively bonded structures are subject to time-varying loads, it is necessary to understand the mechanism associated with fatigue failure of these joints. In an attempt to overcome the lack of information at the low-cycle, high-stress, an investigation of the fatigue of adhesive joints in this region was conducted. The effect of the following variables on the fatigue of adhesive joints was investigated: (a) bondline thickness (b) stress amplitude (c) frequency and (d) test environment.

The polymeric adhesives are viscoelastic materials and exhibit mechanical hysteresis even at moderate temperatures. For this reason, the effect of the environment on the fatigue life of the adhesive joints was investigated. The properties of the adhesive are also known to change with the presence of moisture. In order to investigate the effects of humidity, the specimens were conditioned for 1000 hours in an environmental chamber ($145^0$ F, 85% RH) and then tested in fatigue.

The stress amplitudes, which result in failure of the adhesives in aluminum joints, at the low cycle region of $10^3$ to $10^5$ cycles were determined and all subsequent testing was conducted at these levels (Figure 2). The loading frequency of 2, 5, and 10 Hz will be used. The testing will be conducted at following temperatures: dry conditions at $75^0$ F and $-40^0$ F and wet conditions at $75^0$. Fatigue testing was conducted as per a ëmodifiedí

ASTM D 3166-99. Single lap shear specimens will be used. Aluminum adherends of 0.375" thickness with bondline thickness of 0.02", 0.032î, 0.06" and 0.16" will be tested.

**Task 3: Effect of creep on thick bondline joints**

Adhesives exhibit characteristic creep behavior when subjected to static loads. It is well known that the fatigue properties of the adhesive joints are better at higher frequencies (up to 30Hz) than at lower frequencies. The low frequency ($10^{-4}$ Hz typical) loads accommodate creep deformations, which accumulate over each cycle, leading to relatively very low number of cycles to failure. In order to circumvent this problem, Hart-Smith proposed a design guideline, where the minimum shear stress in the bondline must be less that 10% of its yield strength in shear. However, there is no analysis and limited experimental data to support this claim. Since the fuselage pressurization cycles occur at low frequencies, the above issues have to be suitably addressed by either developing an analysis and/or generating experimental data.

The creep characteristics of the adhesive in the single lap joint configuration will be investigated per a ëmodifiedí ASTM D2294-96. Aluminum adherends of 0.375" thickness with bondline thickness of 0.02", 0.032î, 0.06" and 0.16" will be tested. The tests will be conducted at three different temperatures (150 °F, 180 °F, and 210 °F). Creep tests are conducted using nine ALCOA stressing fixtures, which are calibrated at each test temperature. The nominal shear stress levels are chosen to be 0%, 10%, 15% and 25% of the adhesive yield strength in shear. The test data will be used to generate the delay times $t_d$, and period of logarithmic creep $t_{lc}$ as a function of the stress level and temperature.

**Program B: Effect of bondline thickness variation**

Due to the relatively thin bondlines used in previous investigations, the question of bondline thickness variation hasnít received much attention as well as analysis of a typical joint using simplified methods. The growing concern comes with the recent certification of the new class of general aviation aircraft using substantially greater bondline thickness. Typically, these bondlines have been shown to vary from 0.020î to 0.150î within a single bonded joint. The effect these large variations have with respect to overall joint performance has not been analyzed. This task explores the use of the torsion fixture for an ìelementî test on a bonded structural joint. This torsion fixture was designed for use in this program and to further study such effects as bondline variation and damage tolerance of bonded joints. The torsion fixture designed in this program is shown in Figure (3).

Using the torsion fixture shown in Figure (3), which is designed for this task, 17.25î long single lap joint with a gage width of 0.5î were loaded until failure. Test matrix includes the bondline thickness of 0.05î, 0.10î, 0.16î, and 0.20î (4 specimen each) lap joints. In addition, 0.05î and 0.10î joggle joints (4 specimen each) will be tested. The overall objective for this first task of this investigation is to produce element joint failures using the fixture and compare to simplified analytical predictions. If successful, future work will investigate the bondline variation and damage tolerance philosophy for bonded joints.

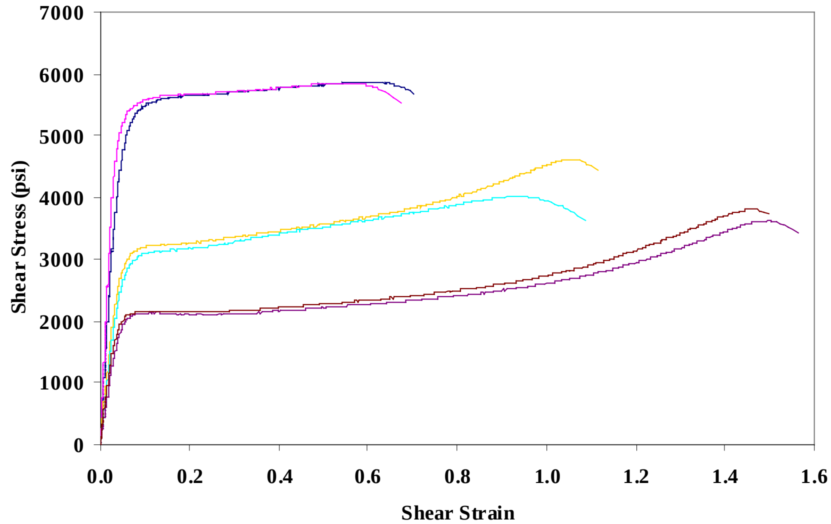


Figure (1): Characteristic shear responses of a typical film adhesive

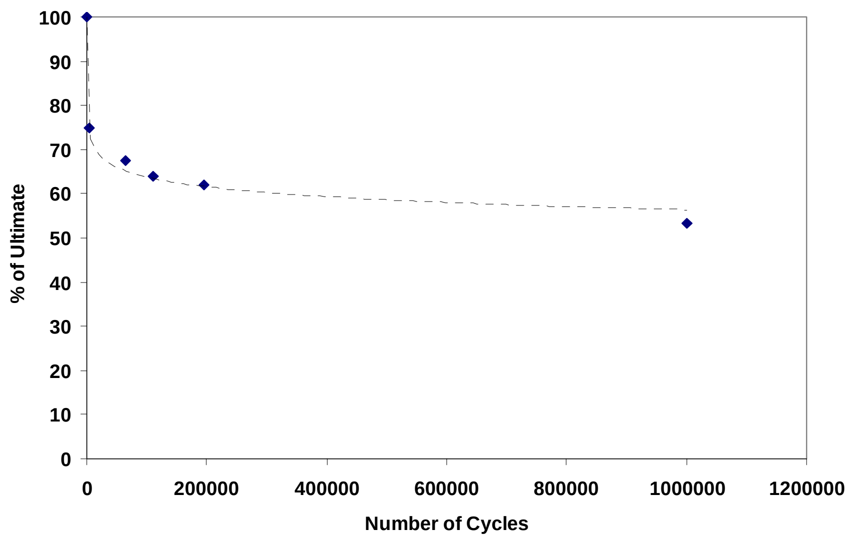


Figure (2): S-N Curve under RTD conditions at 5Hz.

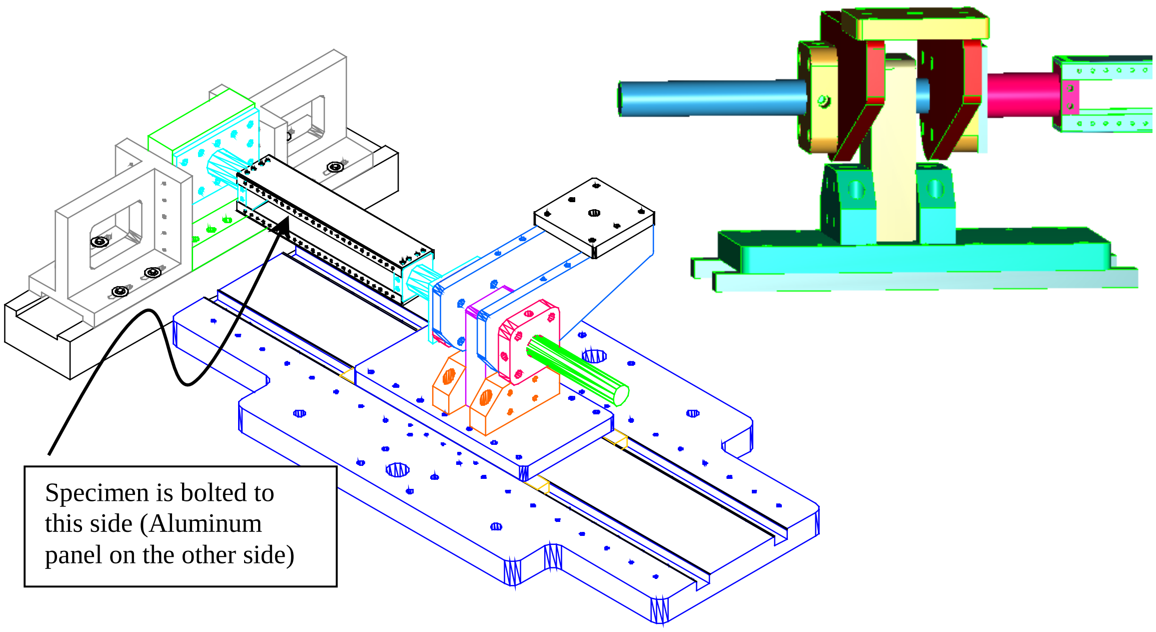


Figure (3):  Box beam lap shear torsion test fixture